PATENT

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of	:	
Tillin et al.	:	Art Unit:
Express Mail: EV337309592US	:	Examiner:
Filed: June 24, 2003	:	

For: POLARISATION ROTATOR, PARALLAX BARRIER, DISPLAY AND OPTICAL MODULATOR

Commissioner for Patents
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Attached please find the certified copy of the foreign application from which priority is claimed for this case:

Country: Great Britain
Application Number: 0215057.1
Filing Date: June 28, 2002

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Statement of inventorship and of right to grant of a patent

The Patent Office

Cardiff Road
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NP9 1RH

1. Your reference JSR.P52138GB

2. 0215057.1

28 JUN 2002

3. Full name of the or of each applicant

Sharp Kabushiki Kaisha

4. Title of the invention

Polarisation Rotator, Parallax Barrier, Display and Optical Modulator

5. State how the applicant *(s)* derived the right from the inventor *(s)* to be granted a patent

By virtue of employment of the inventors by Sharp Laboratories of Europe Limited (SLE), and by agreement with Sharp Kabushiki Kaisha.

6. How many, if any, additional Patents Forms 7/77 are attached to this form? *(see note (c))*

None

7. I/We believe that the person *(s)* named over the page *(and on any extra copies of this form)* is/are the inventor *(s)* of the invention which the above patent application relates to.

Signature
Marks & Clerk

Date
28 June 2002

8. Name and daytime telephone number of person to contact in the United Kingdom

John S. Robinson - 01865 397900

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Patents Form 7/77

Enter the full names, addresses and postcodes of the inventors in the boxes and underline the surnames

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The Patent Office

Cardiff Road
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NP9 1RH

1. Your reference — JSR.P52138GB

2. Patent application number *(The Patent Office will...)* — 0215057.1

28 JUN 2002

3 ...postcode of the or of ... *(underline all surnames)*

Sharp Kabushiki Kaisha
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Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation — Japan 6669113001

4. Title of the invention — Polarisation Rotator, Parallax Barrier, Display and Optical Modulator

5. Name of your agent *(if you have one)* — Marks & Clerk

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Patents ADP number *(if you know it)* — 7271125001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
   See note (d))

Yes

23

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9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	0
Description	12
Claim(s)	4
Abstract	1
Drawing(s)	7

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	1
Request for preliminary examination and search *(Patents Form 9/77)*	1
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature Marks & Clerk — Date 28 June 2002

12. Name and daytime telephone number of person to contact in the United Kingdom: John S. Robinson - 01865 397900

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DUPLICATE

POLARISATION ROTATOR, PARALLAX BARRIER, DISPLAY AND OPTICAL MODULATOR

The present invention relates to a polarisation rotator for rotating the plane of polarisation of linearly polarised light by an arbitrary angle. Such a rotator may be used, for example, as part of a parallax barrier in a display or as an optical modulator in telecommunications. The present invention also relates to parallax barriers, displays and optical modulators including such polarisation rotators.

A known type of liquid crystal device (LCD) is the twisted nematic (TN) type. In such a device, a layer of nematic liquid crystal material is disposed between opposing alignment surfaces, such as rubbed polyimide, which cause the liquid crystal director to twist through 90° from one alignment surface to the other in the absence of an applied field. In the absence of an applied field, the plane of linearly polarised light passing through the device is rotated by 90°.

A relatively low voltage, for example between 0 and 3 volts, is sufficient to switch such TN LCDs. When switched to the non-rotating state, the mid-plane tilt angle of the liquid crystal director rises above a predetermined angle such that the surface regions of the liquid crystal material adjacent the alignment surfaces may be considered as substantially decoupled voltage-dependent optical retarders. Each of these retarders may be represented by a single optic axis along the alignment direction of the alignment surface. The alignment directions of the opposing surfaces are orthogonal to each other so that, provided the pre-tilt of the liquid crystal molecules at the alignment surfaces are substantially equal, the retardations of the surface regions of the liquid crystal layer effectively cancel each other out so that the device provides substantially zero retardation. However, this self-compensation only occurs for twist angles of 90°.

TN LCDs having twists other than 90° are also known. When linearly polarised light is passed through such devices, the polarisation is converted to elliptical polarisation. In order to switch such a device so as to have substantially no effect on the polarisation of

light passing therethrough, a theoretically infinite voltage is required in order to reduce the retardation to zero.

Beynon et al, Journal of the SID, 1999, 7, 71 disclose a technique for calculating linear to circular polarisation conversion in a TN LCD and apply the result to reflective displays comprising a liquid crystal spatial light modulator disposed between a reflector and a polariser.

According to a first aspect of the invention, there is provided a polarisation rotator for rotating the polarisation direction of linearly polarised light by an angle γ different from 90°, comprising a layer of liquid crystal material disposed between a first input alignment surface and a second output alignment surface, the rotator having a mode in which a 90° twist of the liquid crystal director is induced across the layer, the layer having a retardation substantially given by:

$$\tan\left[\pm\frac{\pi}{2}-\gamma\right]=\frac{\tan\left[\pm\frac{\pi}{2}\cdot\sqrt{1+\alpha^2}\right]}{\sqrt{1+\alpha^2}}$$

$$\alpha=\pm\frac{2\cdot\Delta n\cdot d}{\lambda}$$

$$2\theta=\gamma\mp\frac{\pi}{2}$$

where λ is a wavelength of light, Δn is the birefringence of the liquid crystal material, d is the thickness of the layer, and θ is the angle between the polarisation direction of input light and the alignment direction of the first alignment surface.

λ may be a wavelength of visible light.

The rotator may have a further mode in which there is substantially no twist of the liquid crystal director across the layer.

The first and second alignment layers may induce the 90° twist of the director across the layer.

The liquid crystal material may contain a chiral dopant. The chiral dopant may induce the 90° degree twist of the director across the layer.

The liquid crystal material may be a nematic liquid crystal material of positive dielectric anisotropy.

The liquid crystal material may be a smectic liquid crystal material.

The liquid crystal material may be a nematic liquid crystal material of negative dielectric anisotrophy.

The pretilts at the first and second alignment surfaces may be substantially equal to each other.

The rotator may comprise an electrode arrangement for selectively applying a field across at least one region of the layer. The electrode arrangement may comprise an active or passive matrix.

The device may comprise an input polariser having a transmission axis oriented at $-\theta$ to the alignment direction of the first alignment surface.

The rotator may comprise an output polariser having a transmission axis substantially perpendicular to the polarisation direction of the input light.

The rotator may comprise an output polariser having a transmission axis oriented at substantially $(\gamma + n.90)°$ to the polarisation direction of the input light, where n is an integer.

The absolute value of γ may be greater than or equal to 40° and may be less than or equal to 70°. γ may be equal to $\pm 45°$ and $\Delta n.d/\lambda$ may be equal to 0.487. θ may be equal to $\mp 22.5°$. As an alternative, θ may be equal to $\mp 12.5°$.

γ may be equal to $\pm 55°$ and $\Delta n.d/\lambda$ may be equal to 0.55. θ may be equal to $\mp 17.5°$.

The absolute value of γ may be greater than or equal to 175° and may be less than or equal to 180°. γ may be equal to 180°, θ may be equal to $\pm 45°$ and $\Delta n.d/\lambda$ may be equal to 1.415. As an alternative, γ may be equal to $\pm 178°$, θ may be equal to $\pm 44°$ and $\Delta n.d/\lambda$ may be equal to 0.105.

According to a second aspect of the invention, there is provided a parallax barrier comprising a rotator according to the first aspect of the invention.

The barrier may comprise a patterned retarder, such as a halfwave retarder. The retarder may comprise first and second regions and γ may be equal to the included angle between the slow axes of the first and second regions. The included angle may be between 40° and 70°. The slow axes of one of the first and second regions may be parallel or perpendicular to the polarisation direction of the input light. The slow axes of the other of the first and second regions may be oriented at 45° to the polarisation direction of the input light. As an alternative, the slow axes of the other of the first and second regions may be oriented at 55° to the polarisation direction of the input light.

According to a third aspect of the invention, there is provided a display comprising a rotator according to the first aspect of the invention or a barrier according to the second aspect of the invention.

According to a fourth aspect of the invention, there is provided an optical modulator comprising a rotator according to the first aspect of the invention.

It has been found that a TN LCD with a 90° twist can be used to rotate the plane of polarisation of linearly polarised light by any arbitrary angle. The effect may be

modulated (between providing polarisation rotation and providing no polarisation rotation) by means of a relatively low finite voltage. Such a device has many application, for example as part of a parallax barrier in a switchable 2D/autostereoscopic 3D display and as an optical modulator in an optical telecommunications system.

Throughout the present specification, positive values of angles may be either clockwise or anti-clockwise, with negative values then referring to angles in the opposite direction. Also, all angles of polarisation directions and retarder slow axes are expressed "modulo 180°". Thus, each angle β is equivalent to each angle $(\beta \div n.180)°$, where n is any integer. However, in some embodiments, because of the nature of their constructions, a value of β may be preferred over the value of $(\beta + 180°)$ because of improved performance.

The invention will be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a graph of polarisation rotation against retardation;

Figure 2 is a diagram illustrating a polarisation rotator constituting a first embodiment of the invention;

Figure 3 is a cross-sectional view of the rotator of Figure 2;

Figure 4 is a cross-sectional diagram illustrating the use of the rotator of Figure 2 as a display;

Figure 5 is a cross-sectional diagram illustrating the use of the rotator of Figure 2 as part of a parallax barrier in a display which is switchable between a two dimensional (2D) mode and an autostereoscopic three dimensional (3D) mode;

Figure 6 is a diagram illustrating part of the display shown in Figure 5;

Figure 7 is a diagram illustrating a polarisation rotator constituting a second embodiment of the invention; and

Figure 8 is a diagram illustrating a modified part of the display shown in Figure 5.

Like reference numerals refer to like parts throughout the drawings.

It is possible to derive conditions for which an LCD converts a first linear polarisation to any arbitrary different linear polarisation of light, such as visible light, based on technique disclosed by Beynon et al, Journal of the SID 1999, 7, 71. By setting the twist angle ϕ to + or - 90° (+ or - $\pi/2$), the following condition relates the angle γ of rotation of the linear polarisation azimuth (with respect to the incident polarisation azimuth) to the retardation of a nematic liquid crystal layer:

$$\tan\left[\pm\frac{\pi}{2}-\gamma\right]=\frac{\tan\left[\pm\frac{\pi}{2}\cdot\sqrt{1+\alpha^2}\right]}{\sqrt{1+\alpha^2}}$$

$$\alpha=\pm\frac{2\cdot\Delta n\cdot d}{\lambda}$$

$$2\theta=\gamma\mp\frac{\pi}{2}$$

where d is the thickness of the layer, λ is the wavelength of light, Δn is the birefringence of the liquid crystal material, and θ is the angle between the azimuth of the incident linear polarisation and the input director of the liquid crystal. This is represented graphically in Figure 1, which plots the rotation angle γ as a function of the retardation $\Delta n.d/\lambda$ for the first three "branches" or solutions for positive values of γ. Negative values of γ may be obtained by reflecting the graph of Figure 1 about the x axis but, as a polarisation rotation of +45° is substantially identical to a polarisation rotation of -135°,

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these curves have not been shown. The curves are periodic in positive or negative γ and the number of branches is infinite in extent in terms of retardation. The crossing points for $\gamma = 90°$ are the known Gooch-Tarry 90° TN minima.

The polarisation rotator shown in Figure 2 is arranged to provide a rotation of linear polarisation by 45°. The rotator comprises an input polariser 1 which receives unpolarised input light 2 and has a transmission axis 3 oriented vertically and defining a reference direction. As shown in Figure 3, the polariser 1 is formed on or attached to a first liquid crystal (LC) substrate 4 which, together with a second substrate 5, defines a cell containing a liquid crystal layer 6. The inner surfaces of the substrates 4 and 5 have formed thereon conductive transparent electrodes 7 and 8, for example made of indium tin oxide (ITO), and alignment layers 9 and 10, for example comprising rubbed polyimide layers. The rubbing directions of the alignment layers 9 and 10 are orthogonal to each other.

The alignment direction of the alignment layer 9 is illustrated at 11 in Figure 2 and is oriented at -22.5° with respect to the transmission axis 3. The alignment direction 12 of the alignment layer 10 is therefore oriented at +67.5° with respect to the transmission axis 3.

The liquid crystal material of the layer 6 is of nematic type and the alignment layers 9 and 10 induce, in the absence of an applied field across the layer 6 between the electrodes 7 and 8, a -90° twist to the liquid crystal director from the alignment layer 9 to the alignment layer 10. The alignment layers are also such that the pre-tilts at the surface regions of the layer 6 have substantially the same magnitude. A small amount of chiral dopant may be used to induce a (positive or negative) twist in the liquid crystal as desired.

The liquid crystal layer 6 has a retardation $\Delta n.d/\lambda = 0.487$ and, in the absence of an electric field applied between the electrodes 7 and 8, the rotator rotates the plane of polarisation of the light from the polariser 1 by 45° as illustrated at 13 in Figure 2. When a sufficiently large voltage, for example of the order of 3 volts, is applied

between the electrodes 7 and 8 across the layer 6, the mid-plane tilt angle of the liquid crystal director in the middle region of the layer 6 rises to a value such that the surface regions of the layer 6 act as substantially decoupled voltage dependent optical retarders. The optic (slow) axes of these regions are then effectively determined by the rubbing directions of the alignment layers 9 and 10 and so are orthogonal to each other. The retardations of these decoupled retarders thus cancel each other out and the device has substantially no effect on the polarisation of light passing therethrough. In this state, the device passes the vertically polarised light from the polariser 1 substantially without rotating or changing the polarisation state of the light.

As shown in Figure 4, a rotator of this type may be used as a pixellated liquid crystal display. The electrode 7 is divided into individual pixel electrodes, each of which is associated with a thin film transistor (TFT) 14 forming part of an active matrix addressing arrangement of the display. Colour filters 15, such as red, green and blue filters, are formed on the substrate 5 in order to provide a colour display and an analysing polariser 16 is formed or disposed on the outer surface of the substrate 5. The transmission axis of the polariser 16 is orthogonal to the transmission axis of the polariser 1 so that, when a sufficient electric field is applied across a pixel, the polariser 16 substantially extinguishes light passing through the pixel, which therefore appears in its dark or black state. When the applied field is removed, the pixel rotates the plane of polarisation by 45° so that the polarisation plane is oriented at 45° with respect to the transmission axis of the polariser 16. The pixel therefore appears in its bright or maximally transmissive state.

Figure 5 illustrates the use of the rotator in a display of the type disclosed in our copending British patent application filed on the same day as the present application, entitled "Optical device and display", and bearing reference number P52107GB. The display comprises a backlight 20 disposed behind the input polariser 1 and a switching LCD in the form of the rotator shown in Figure 2. Light from the rotator passes to a patterned retarder 21 formed on a glass substrate 22. The patterned retarder 21 has first regions such as 23 for acting as parallax barrier slits and second regions 24 for acting as "opaque" barrier regions in the autostereoscopic 3D mode of the display.

The orientations of the various axes are shown in Figure 6. The transmission axis 3 of the polariser 1 is oriented at 45°. The alignment direction 11 of the alignment layer 9 is oriented at 22.5°. The alignment direction 12 of the alignment layer 10 is oriented at 112.5°. The regions 23 have slow axes 25 oriented at 90° whereas the regions 24 have slow axes 26 oriented at 45°. An analysing polariser 27 for the switching LCD has a transmission axis 28 oriented at 135° i.e. orthogonal to the transmission axis 3 of the input polariser 1.

The display further comprises a pixellated spatial light modulator (SLM) in the form of a "display LCD". The display LCD comprises a pixellated liquid crystal layer 30 disposed between substrates 31 and 32. Alignment layers, electrodes, colour filters and addressing arrangements are not shown in Figure 5 for the sake of clarity. The polariser 27 acts as an input polariser for the LCD and an output polariser 33 is provided on the outer surface of the substrate 32. The display LCD may be of any suitable type for displaying images.

In the 3D mode, the polarisation rotator is switched off by applying a voltage across the liquid crystal layer 6 so that no polarisation rotation takes place. Light from the polariser with the polarisation direction parallel to the transmission axis 3 passes through the rotator with its polarisation unchanged and likewise passes through the regions 24 with its polarisation unchanged. The transmission axis 28 of the polariser 27 is perpendicular to the polarisation so that light passing through the regions 24 is substantially extinguished.

Light incident on the regions 23 is polarised at -45° with respect to the optic axis 25. The polarisation direction is rotated by 90° through the regions 23 so as to be aligned with the transmission axis 28 of the polariser 27. The slits regions 23 thus appear substantially transparent so that the retarder 21 and associated elements act as a rear parallax barrier.

In the 2D mode, no field is applied across the liquid crystal layer 6. This layer therefore provides 45° of polarisation rotation so that the polarisation direction of light incident on the patterned retarder 21 is 90°. The regions 23 do not affect the polarisation direction whereas the regions 24 cause the polarisation to be rotated by -90°. Light from both the regions 23 and 24 therefore has polarisation directions oriented at 45° with respect to the transmission axis 28 of the polariser 27, so that the display LCD receives light of substantially the same intensity from the regions 23 and 24. The barrier structure is therefore substantially invisible and the display operates in the 2D mode.

Figure 7 illustrates a modification to the arrangements shown in Figures 5 and 6 in order to provide an arrangement for use in the display disclosed in our further copending application filed on the same day as the present application, also entitled "Optical device and display", and bearing reference number P52115GB. In such a display, the brightness in the 2D mode is substantially increased at the expense of a smaller decrease in brightness of the bright state of the 3D mode. A polarisation rotation of 55° is required for such a display and the relevant orientations are illustrated in Figure 7. Thus, the alignment direction 11 is oriented at 27.5°, the alignment direction 12 is oriented at 117.5°, and the optic axis 25 is oriented at 100°. The other orientations are as shown in Figure 6. In order to provide the 55° rotation, the retardation $\Delta n.d/\lambda$ of the liquid crystal layer is 0.55.

Although an example with 55° of polarisation rotation is illustrated in Figure 7, other rotations may be provided as necessary according to the needs of the particular example of the display.

In general, the required polarisation rotation angle is the same as the included angle between the slow axes 25 and 26 of the retarder regions 23 and 24, respectively.

Figure 8 illustrates an arrangement which differs from those shown in Figures 5 and 6 in that the orientation and retardation are changed to optimise the output of the patterned retarder 21 so as to achieve substantially identical spectral responses from the regions 23 and 24 in the 2D mode. The liquid crystal layer 6 has a retardation $\Delta n.d/\lambda=0.415$,

the alignment direction 11 is oriented at 57.5°, and the alignment direction 12 is oriented at 147.5°.

The embodiments described hereinbefore use a layer of nematic liquid crystal material having positive dielectric anisotropy. In such embodiments, the alignment surfaces for the liquid crystal material provide relatively small pre-tilt angles whose azimuths are orthogonal to each other. In the absence of an applied field, there is a 90° twist in the liquid crystal director from one alignment surface to the other.

Other liquid crystal modes may be used, for example in the arrangements shown in the drawings, with modifications as appropriate to the actual mode of operation. For example, the liquid crystal material may comprise a nematic material of negative dielectric anisotropy and the alignment surfaces may be arranged to induce a substantially homeotropic orientation of the liquid crystal director in the absence of an applied field. The liquid crystal adjacent the alignment surfaces has a high pre-tilt, for example close to 90°. In the absence of an applied field, the homeotropic alignment results in substantially no change to the polarisation state of light passing through the layer.

When an electric field is applied across the layer of such a material, the pre-tilt caused by the alignment surface and/or a structure such as the electrode structure below the alignment surface causes the liquid crystal directors of the molecules near the alignment surfaces to be reoriented in a predetermined direction. The liquid crystal material may also include a chiral dopant whose concentration may be such as to induce a pitch of twist in the liquid crystal layer such that the ratio of the pitch to the thickness of the layer is substantially equal to 0.25. When an electric field greater than a predetermined voltage is applied across the layer, the layer takes up a substantially 90° twist. Thus, in such embodiments, the polarisation rotator is active in the presence of an applied field and is inactive in the absence of an applied field.

It is also possible to provide embodiments in which the liquid crystal material is of the smectic type.

A polarisation rotator of the type shown in Figure 2 may be used in other applications, one example of which is as an optical modulator, for example in telecommunication applications. For example, the rotator may be used to provide a π phase modulator by selectively providing a polarisation rotation of 180°, which is equivalent to inducing a π phase lag in linearly polarised light. In order to produce a 180° polarisation rotation, the retardation $\Delta n.d/\lambda$ of the liquid crystal layer may be made 1.414 and the angle between the azimuth of the incident linear polarisation and the input director of the liquid crystal may be made 45°. The phase change provided by the modulator may be controlled by a relatively low modulating voltage, for example about 3 volts, which is compatible with CMOS technology.

As an alternative, a polarisation rotation close to 180 ° may be used to achieve almost the same effect. For example, a rotation of 178° may be achieved with $\Delta n.d/\lambda = 0.105$ and $\theta = 44°$. Such a low retardation allows the use of a very thin liquid crystal layer which, in turn, provides a very rapid response time. This is advantageous in telecommunication applications, where fast switching is very desirable.

CLAIMS:

1. A polarisation rotator for rotating the polarisation direction of linearly polarised light by an angle γ different from 90°, comprising a layer of liquid crystal material disposed between a first input alignment surface and a second output alignment surface, the rotator having a mode in which a 90° twist of the liquid crystal director is induced across the layer, the layer having a retardation substantially given by:

$$\tan\left[\pm\frac{\pi}{2}-\gamma\right]=\frac{\tan\left[\pm\frac{\pi}{2}\cdot\sqrt{1+\alpha^2}\right]}{\sqrt{1+\alpha^2}}$$

$$\alpha=\pm\frac{2\cdot\Delta n\cdot d}{\lambda}$$

$$2\theta=\gamma\mp\frac{\pi}{2}$$

where λ is a wavelength of light, Δn is the birefringence of the liquid crystal material, d is the thickness of the layer, and θ is the angle between the polarisation direction of input light and the alignment direction of the first alignment surface.

2. A rotator as claimed in claim 1, in which λ is a wavelength of visible light.

3. A rotator as claimed in claim 1 or 2, having a further mode in which there is substantially no twist of the liquid crystal director across the layer.

4. A rotator as claimed in any one of the preceding claims, in which the first and second alignment layers induce the 90° twist of the director across the layer.

5. A rotator as claimed in any one of the preceding claims, in which the liquid crystal material contains a chiral dopant.

6. A rotator as claimed in claim 5, in which the chiral dopant induces the 90° twist of the director across the layer.

7. A rotator as claimed in any one of the preceding claims, in which the liquid crystal material is a nematic liquid crystal material of positive dielectric anisotropy.

8. A rotator as claimed in any one of claims 1 to 6, in which the liquid crystal material is a smectic liquid crystal material.

9. A rotator as claimed in any one of claims 1 to 6, in which the liquid crystal material is a nematic liquid crystal material of negative dielectric anisotropy.

10. A rotator as claimed in any one of the preceding claims, in which the pretilts at the first and second alignment surfaces are substantially equal to each other.

11. A rotator as claimed in any one of the preceding claims, comprising an electrode arrangement for selectively applying a field across at least one region of the layer.

12. A rotator as claimed in claim 11, in which the electrode arrangement comprises an active or passive matrix.

13. A rotator as claimed in any one of the preceding claims, comprising an input polariser having a transmission axis oriented at $-\theta$ to the alignment direction of the first alignment surface.

14. A rotator as claimed in any one of the preceding claims, comprising an output polariser having a transmission axis substantially perpendicular to the polarisation direction of the input light.

15. A rotator as claimed in any one of claims 1 to 13, comprising an output polariser having a transmission axis oriented at substantially $(\gamma + n.90)°$ to the polarisation direction of the input light, when n is an integer.

16. A rotator as claimed in any one of the preceding claims, in which $40° \leq |\gamma| \leq 70°$.

17. A rotator as claimed in claims 16, in which $\gamma = \pm 45°$ and $\Delta n.d/\lambda = 0.487$.

18. A rotator as claimed in claim 17, in which $\theta = \mp 22.5°$.

19. A rotator as claimed in claim 17, in which $\theta = \mp 12.5°$.

20. A rotator as claimed in any one of claims 1 to 6, in which $\gamma = \pm 55°$ and $\Delta n.d/\lambda = 0.55$.

21. A rotator as claimed in claim 11, in which $\theta = \mp 17.5°$.

22. A rotator as claimed in any one of claims 1 to 15, in which $175° \leq |\gamma| \leq 180°$.

23. A rotator as claimed in claim 22, in which $\gamma = 180°$, $\theta = \pm 45°$ and $\Delta n.d/\lambda = 1.414$.

24. A rotator as claimed in claim 22, in which $\gamma = \pm 178°$, $\theta = \pm 44°$ and $\Delta n.d/\lambda = 0.105$.

25. A parallax barrier comprising a rotator as claimed in any one of claims 1 to 21.

26. A barrier as claimed in claim 25, comprising a patterned retarder.

27. A barrier as claimed in claim 26, in which the retarder is a halfwave retarder.

28. A barrier as claimed in claim 27, in which the retarder comprises first and second regions and γ is equal to the included angle between the slow axes of the first and second regions.

29. A barrier as claimed in claim 28, in which the included angle is between 40° and 70°.

30. A barrier as claimed in claim 29, in which the slow axis of one of the first and second regions is parallel or perpendicular to the polarisation direction of the input light.

31. A barrier as claimed in claim 30, in which the slow axis of the other of the first and second regions is oriented at 45° to the polarisation direction of the input light.

32. A barrier as claimed in claim 30, in which the slow axis of the other of the first and second regions is oriented at 55° to the polarisation direction of the input light.

33. A display comprising a rotator as claimed in any one of claims 1 to 24 or a barrier as claimed in any one of claims 25 to 32.

34. An optical modulator comprising a rotator as claimed in any one of claims 1 to 24.

ABSTRACT

POLARISATION ROTATOR, PARALLAX BARRIER, DISPLAY AND OPTICAL MODULATOR

(Figure 2)

A polarisation rotator is provided for rotating the polarisation direction of linearly polarised light by any arbitrary angle other than 90°. The device comprises a layer of liquid crystal material disposed between alignment surfaces. In one mode, a 90° twist is induced in the liquid crystal director. An expression is provided for relating the retardation of the layer to the amount of polarisation rotation and the angle between the polarisation direction of incident light and the alignment direction (11) at the input side of the liquid crystal layer.

28-JUN-2002 15:08 FROM MARKS&CLERK

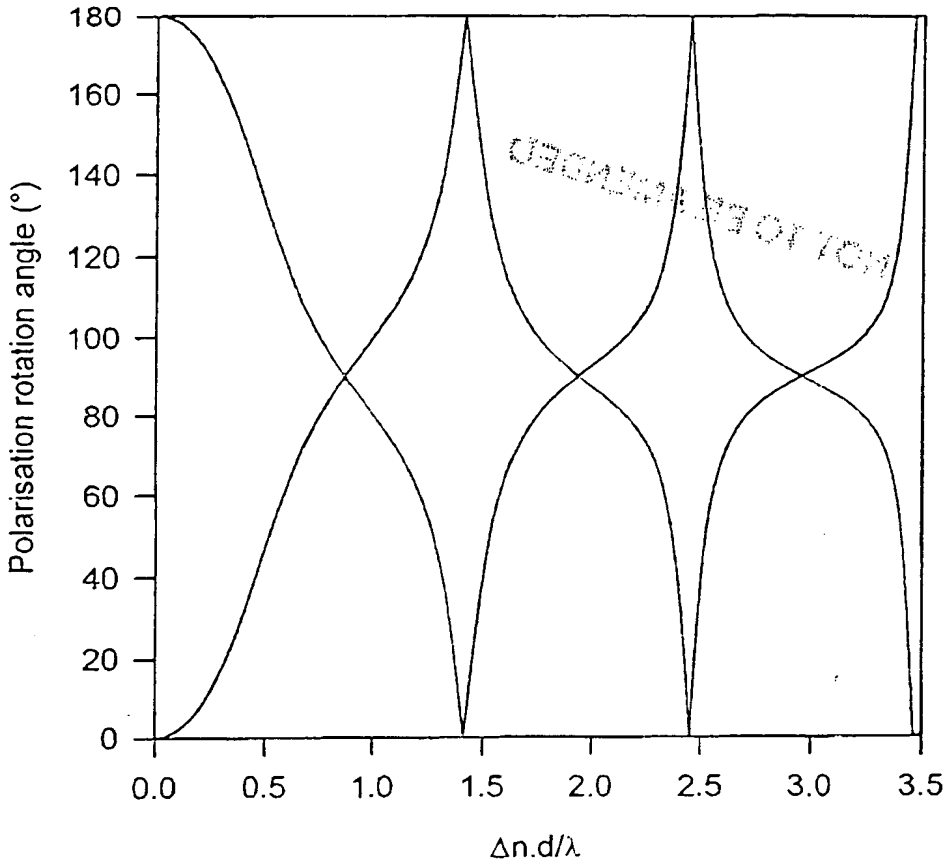
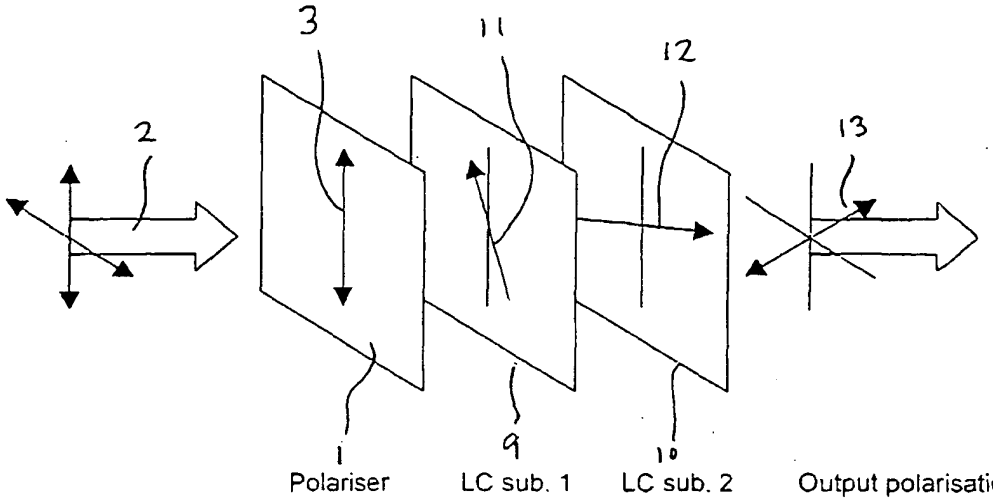

180
160
140
120
100
80
60
40
20
0
Polarisation rotation angle (°)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Δn.d/λ

Figure 1



Viewed from light source, orientation θ with respect to polariser transmission axis:

0° -22.5° +67.5° +45°

Figure 2

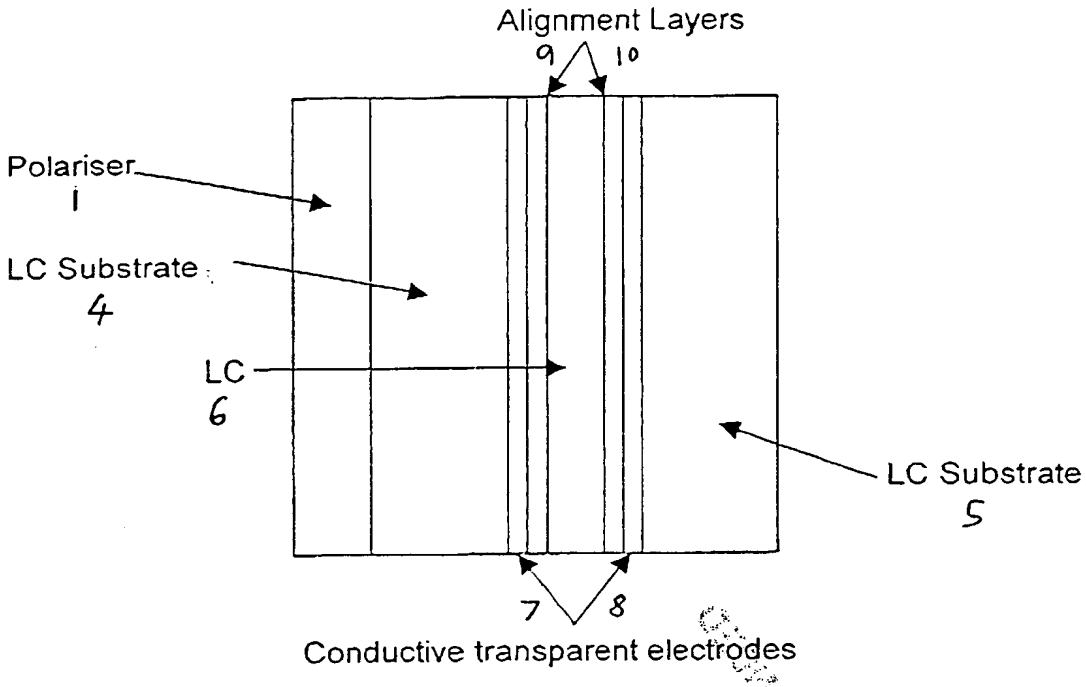


Figure 3

COPY SUBMITTED AS FILED

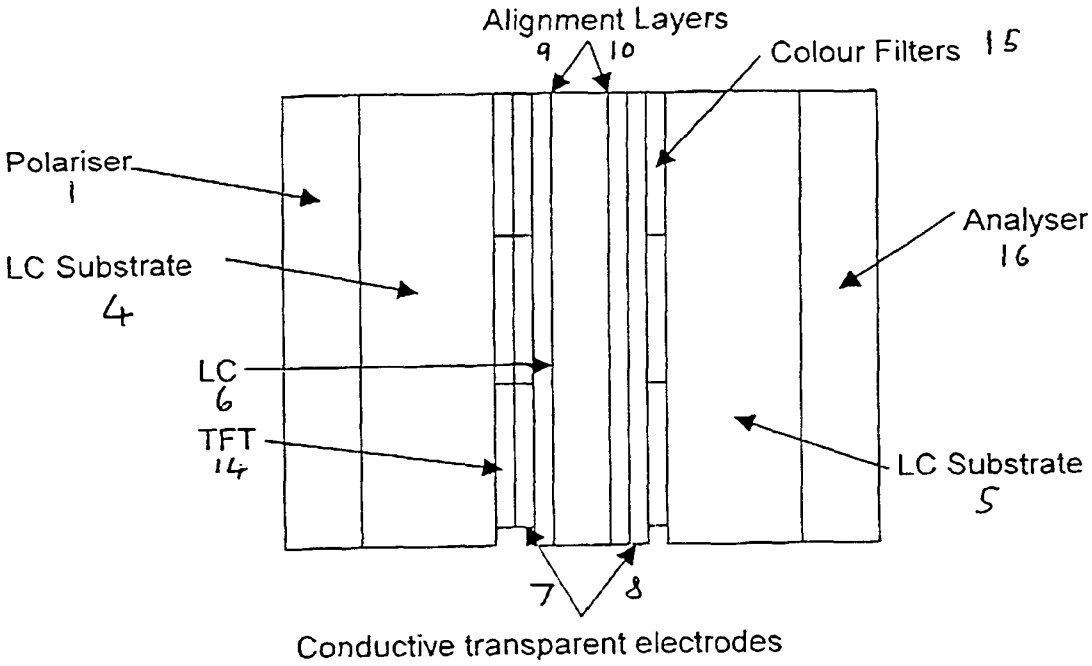


Figure 4

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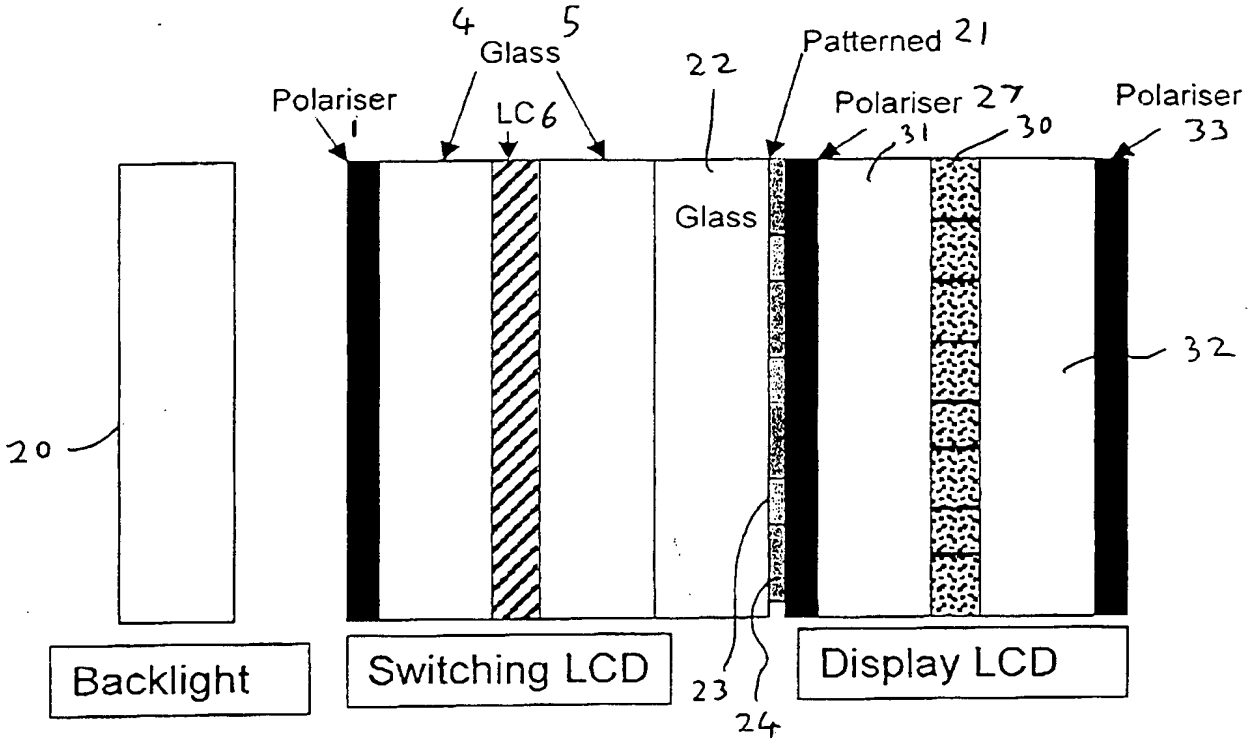
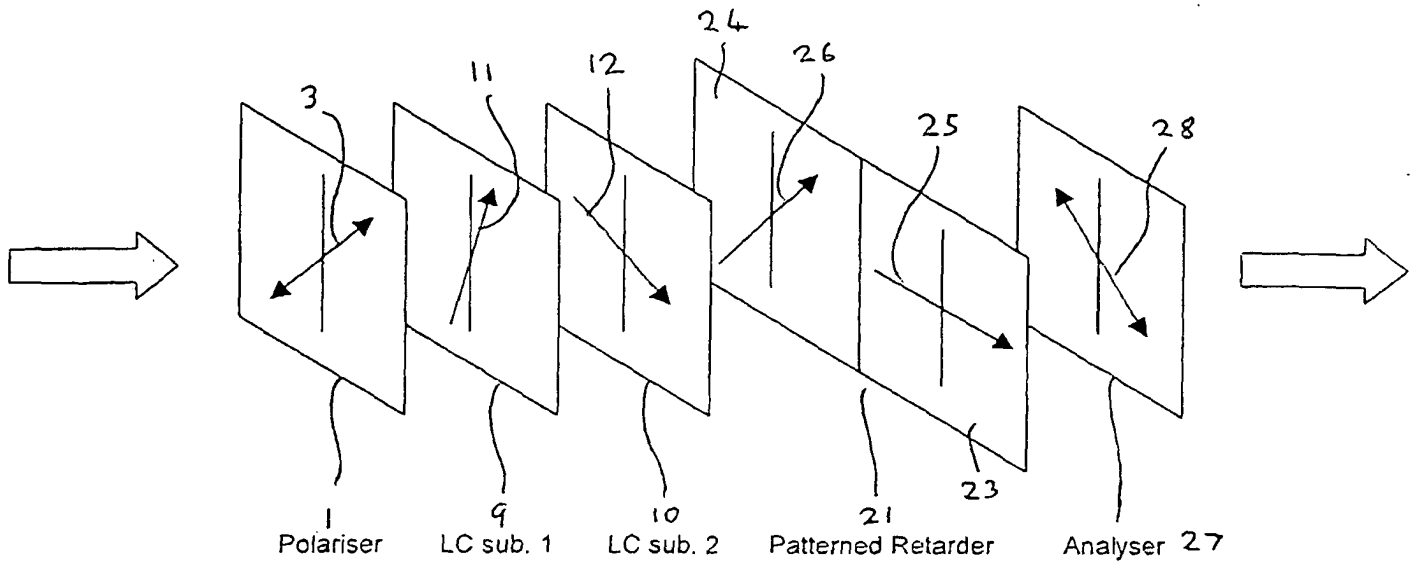

4
5
Glass
Patterned 21
22
Polariser
1
LC 6
Polariser 27
31
30
Polariser
33
Glass
32
20
Backlight
Switching LCD
23
24
Display LCD

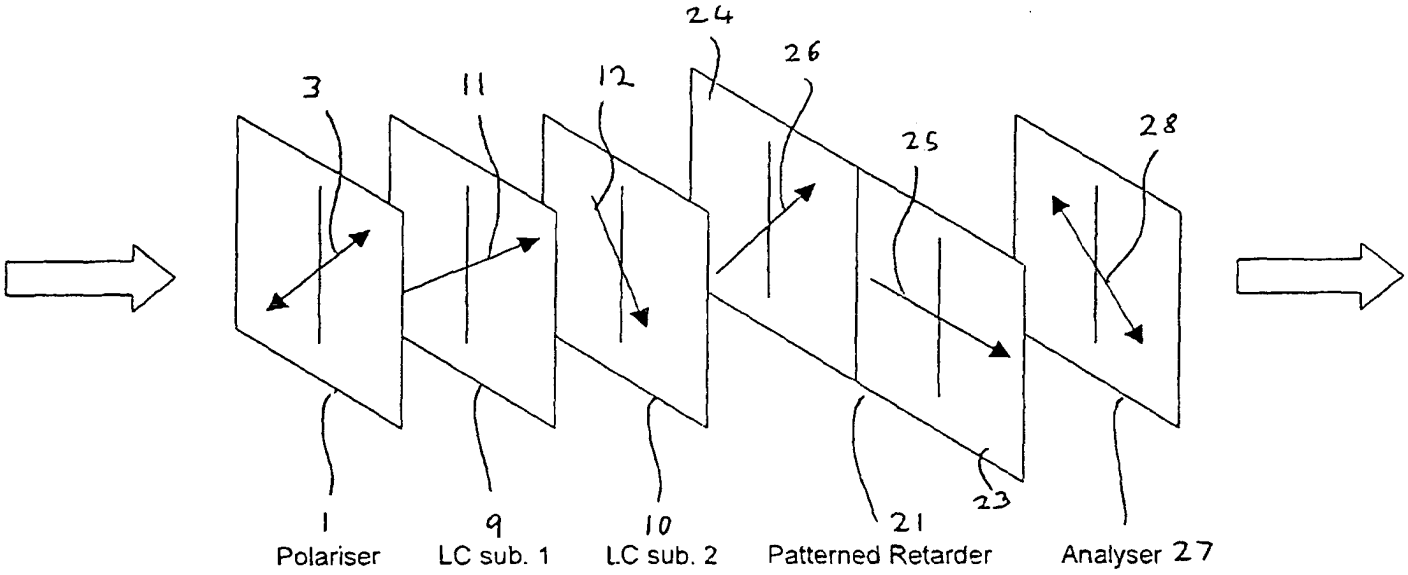
Figure 5



Viewed from light source, orientation θ:

45° 22.5° 112.5° 45° 90° 135°

Figure 6



Viewed from light source, orientation θ:

45° 57.5° 147.5° 45° 90° 135°

Figure 8

Viewed from light source, orientation θ:

45°	27.5°	117.5°	45°	100°	135°

Figure 7